

Effectiveness of Passive Cooling Paints in Mediterranean Climates[#]

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ABSTRACT

Rising global temperatures have intensified the need to reduce energy consumption in the built environment. Passive cooling measures, such as cooling paints and films, can mitigate indoor overheating by reflecting solar radiation. While their capabilities have been demonstrated particularly in tropical climates, their effectiveness in Mediterranean regions remains underexplored. Through building simulations conducted in the software IES VE, this paper evaluates the performance of cooling paints using historical weather data of Mediterranean locations. Results indicate that these paints can reduce annual average indoor temperatures by 1.98 ± 0.86 °C, contributing to improved thermal comfort and reduced cooling demand. These findings showcase the potential of cooling paints as a promising passive strategy to enhance building energy performance, particularly in countries facing elevated and prolonged heat events.

Keywords: Cooling demand, passive cooling strategies, cooling paint, IES VE, Mediterranean climate.

NOMENCLATURE

Abbreviations:

ACH Air change per hour

Symbols:

U Thermal transmittance [$W/(m^2 \cdot K)$]

R_T Thermal resistance [$(m^2 \cdot K)/W$]

h^{-1} Unit of air change per hour

1. INTRODUCTION

The need for cooling in residential buildings around the globe is on the rise. As temperatures reach extremes never experienced before in locations with buildings not well-suited for such conditions [1], the amount of energy required to maintain indoor temperatures at comfortable levels keeps constantly climbing [2]. This change can be observed at different intensities based on geographical location and environmental conditions.

Extreme temperatures can have adverse effects on the general population, posing a health hazard (i.e. heatstroke) [3], and affect transport and building infrastructure [4]. The effects can be managed with a wide range of active cooling methods like heating, ventilation, and air conditioning systems, but these are energy-demanding and may be thus costly.

Passive cooling facilitates management of thermal energy without components consuming additional energy. Passive cooling may vary based on climate, architecture and traditions of specific regions and helps in decreasing the overall cooling demand of buildings. For instance, near-infrared reflective paints have been found to highly effectively reflect solar radiation [5], [6]. Such an effect is most desired during hot days and periods such as heatwaves, but the cooling effects are year-round. Certain radiative paints, which in addition to reflect sunlight also emit heat as infrared radiation, enable surfaces to remain cooler than ambient temperatures [7].

While there have been studies reported in the literature on the effectiveness of cooling paints to reduce the indoor temperature of dwellings located at tropical climates [5,8], there is a significant gap when it comes to Mediterranean climates. This is relevant as the effect of cooling paints may be considerable in Mediterranean countries as these exhibit substantial cooling demand.

In this paper the effects of cooling paints on indoor temperature and thermal demand of typical Mediterranean dwellings are investigated. To this end, the software IES VE was used alongside historical weather data. An actual layout of a flat in Athens, Greece, was chosen and a comparison made with a similar dwelling located in Marseille, France. By studying the impacts of the cooling paint, it was possible to understand the most effective building orientation, use and location for paint deployment to mitigate the effects of overheating and reduce energy consumption during extreme heat.

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2. LITERATURE REVIEW AND METHODS

2.1 Locational Data

The climate conditions in Athens, Greece, are best described as Mediterranean and fall under the ‘Csa’ category in the Köppen-Geiger climate classification, as shown in Fig. 1. Areas in this category are characterised by warm temperate climate with dry and hot summers [9]. These locations can face extreme temperatures in the summer months—a time where the average temperature of a least one month is above 22 °C.

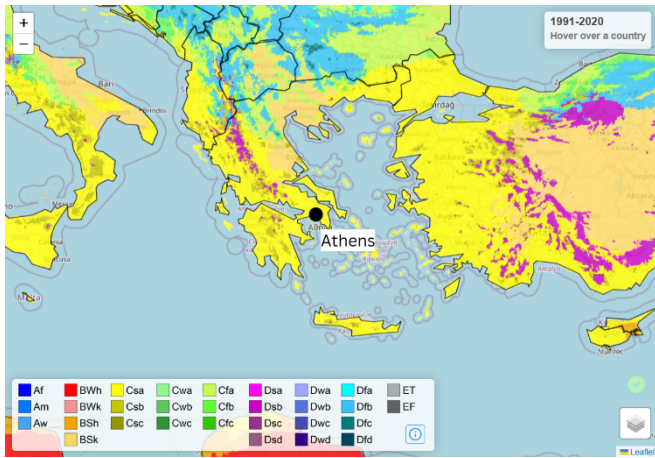


Fig. 1 Köppen-Geiger classification map of Greece [9]

Athens is the capital city of Greece and is in the region of Attica. According to statistical data from ELSTAT (Hellenic Statistics Agency), Attica is the most populated municipality in Greece, with 36% of the population residing there [10]. Athens has thus been identified as a relevant location for conducting the study in this paper.

To provide additional insight into the usefulness of cooling paints in the Mediterranean area, the city of Marseille, France, has been also considered for comparison. Marseille’s weather is also classified as ‘Csa’ in the Köppen-Geiger classification (see Fig. 2).

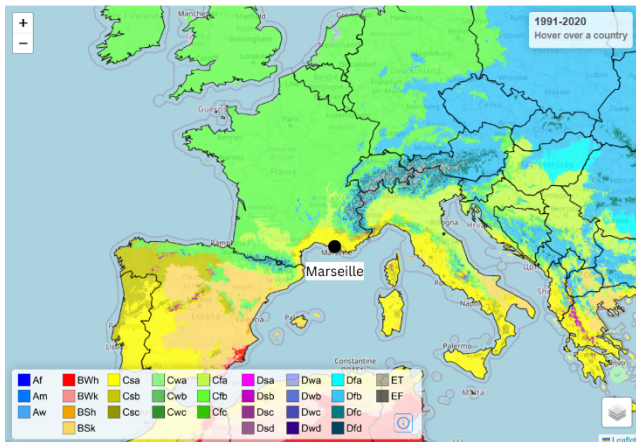


Fig. 2 Köppen-Geiger classification map of France [9]

Historical weather data were sourced from the ERA5 Copernicus Database [11] for 2022 in which large parts of Europe were affected by heatwaves. These were converted into an EPW file and used for the simulations.

2.2 Dwelling Properties

A flat was chosen for this study as it represents a very common type of dwelling in Athens. Most flats in Greece have balconies which can be accessed from large doors. As shown in Fig. 3, illustrating the floorplan of the selected flat, there is balcony access (see the opening on the bottom left of the schematic). Typically, balconies come with awnings, and these have been considered alongside the floorplan.

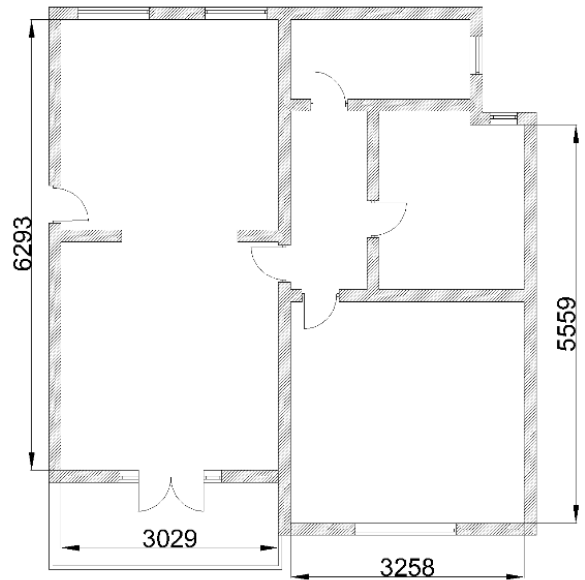


Fig. 3 Floorplan, adapted from [12]

The orientation of a building, when combined with other factors such as window placement and size, can affect the indoor temperature [13]. To assess this, two different orientations, north and east, have been considered in this paper to determine the most optimal use of cooling paint coatings.

To develop a suitable model to accurately represent the dwelling, the thermal transmittances, or U-values, of different components of the building envelope have been considered. A U-value is a measure employed to calculate the thermal efficiency of a material [14].

The current maximum allowed U-values for Greek buildings were sourced from relevant documents and guidance issued by the Greek Government [15], [16], [17], along with historical values from previously issued requirements. In the guidance document, the country is split in “climate zones”. Athens is located in climate Zone B. All U-values here used thus refer to Zone B and are provided in Table 1.

Table 1: U-value [W/(m²·K)] of construction materials.

Foundations	Walls	Windows/doors	Roofs
1.60	0.60	3.00	0.40

Air exchange rates are important for indoor temperature regulation. These can be integrated into the simulation model (described in Section 2.4) in units of air changes per hour (ACH). In addition, measured air flow rates in dwellings differ between summer and winter due to the tendency of residents to open windows as a passive cooling technique in the summer [18]. Based on this consideration and further information available in [18], a value of 1.5 ACH was selected.

For simplicity, an identical dwelling as the one shown in Fig. 3 and with U-values in Table 1 has been considered for Marseille. This assumption is reasonable as flats are also common in Marseille. In other words, a similar building model was developed for both geographical locations to eliminate non-climate related variables from the comparison. A weather file specific to each location was however considered.

2.3 Cooling paints

Cooling paints constitute an effective passive cooling mechanism to reduce the indoor temperature of buildings without the need for additional energy input. Their use on exteriors is attractive as the cooling efficiency may be improved without requiring structural changes in the construction. By reducing indoor temperature, reliance on active cooling solutions may be in turn decreased, leading to reduced electricity bills.

There is a wide variety of reflective pigments and paints which have been experimentally developed [19]. They essentially inhibit heat gain from sunlight, reflecting wavelengths of 0.3 to 2.5 μm [20]. Their chemical composition gives them their high reflectivity rates.

While reflective paints mainly reflect incoming solar radiation away from a building envelope, radiative paints combine solar reflectivity with high thermal emissivity into the atmospheric window at wavelengths of 8 to 13 μm —enhancing a cooling effect as the atmosphere’s transparency to these wavelengths prevents thermal radiation to be re-radiated back [21]. This enables actively cooling a surface below ambient temperature.

In this paper, a cooling paint based on a barium sulphate pigment (BaSO_4) has been considered. This paint has been reported to have a total solar reflectance of ~98% [22] and such parameter has been incorporated into the building simulation models. For simplicity, the thermal emission properties of the paint have been ignored and fall out of the scope of the paper.

2.4 IES VE

To simulate the effects of cooling paints on the dwelling presented in Section 2.2, the software IES VE was adopted. IES VE was selected as it is widely used in the construction industry and has a range of capabilities in designing buildings and assessing their thermal efficiency. For instance, several parameters can be adjusted to ensure a realistic simulation.

Although other software packages to simulate the energy performance of buildings such as EnergyPlus [23], DesignBuilder [24] and TRNSYS [25] are available, IES VE offers advanced solar simulation capabilities [26]. IES VE conforms to international standards such as ISO 52000 and hence complies with European standards (DIN EN 12831-1) on building performance [27–29] and UK guidance by CIBSE [30].

To ensure the validity of simulation results, a verification model was developed following the methodology presented in [31]. Specifically, a north-facing flat reported in the reference was selected for replication. A floorplan was used to reconstruct the dwelling, together with the same thermal properties and weather data. The model was then simulated at a fixed set-point temperature of 21 °C to calculate the hourly thermal demand of the dwelling. These results were compared with the published simulation outputs for the same case, shown in Fig. 14(a) of [31]. The root mean squared error of hourly thermal demand between the recreated model and the published results was 10.517 W, which lies within acceptable error margins.

2.5 Modelling approach

To simulate the flat under study, the floorplan shown in Fig. 3 was traced on AutoCAD, converted to a DXF format and imported to IES VE. Adjacent buildings and stories were also included to accurately portray a block of flats, as shown in Fig. 4.

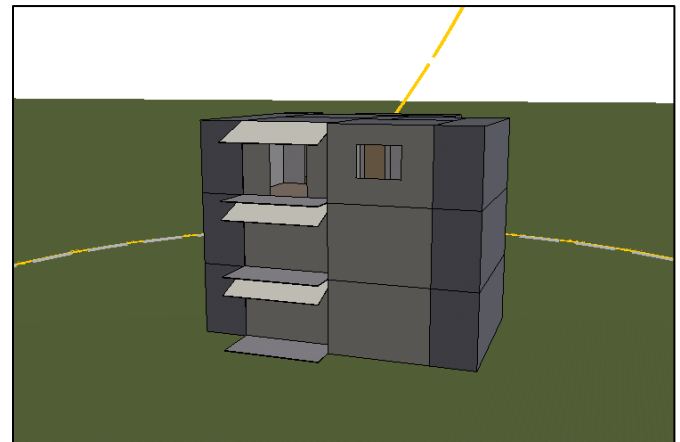


Fig. 4 Block of flats built in IES VE.

An initial baseline simulation was performed with the selected weather file for Athens to determine key indicators such as heating and cooling loads, along with the internal temperature of the flat. These outputs formed the basis for evaluating the paint's effectiveness.

It was necessary to also calculate the solar radiation and sun path to understand their impact on the model and to quantify the effects of the cooling paint. To achieve this, in addition to the main simulation, a SunCast [32] simulation was conducted using the chosen weather file. Results from the SunCast simulation were then linked to the main simulation in IES VE.

To recreate the cooling effect of the paint, the reflectivity of the outer surfaces of the flat were adjusted by altering the solar absorbance of relevant walls and roof on the IES VE model. As highlighted in Section 2.3, a paint with reflectivity at 98% was chosen. Hence, the solar absorbance was selected as 0.02. This choice was made to incorporate properties of a commercially available paint for use in residences. When simulating a flat with no cooling paint layer, the solar absorbance was the default value for a standard beige plaster [33].

For the results shown in Section 3, thermal demand represents an estimate of the thermal energy required for heating or cooling to maintain a constant indoor temperature of 21 °C. Negative values represent cooling demand (i.e. energy required to cool the space), while positive values represent heating demand.

3. RESULTS AND DISCUSSION

3.1 Flat in Athens, Greece

The application of externally applied cooling paint was evaluated for its impact on reducing internal temperature and thermal energy demand in flats with north-facing and east-facing orientations. Simulation results are shown in Figs. 5 and 6 for the whole year 2022. Results without cooling paint are shown with a blue trace, whereas a green trace shows results when a cooling paint has been applied.

3.1.1 Reduction in internal temperature

For the north-facing flat, the paint yielded an average annual internal temperature reduction of 1.97 °C, with a peak summer difference of 4.23 °C recorded on 28 June at 06:00. The influence of the paint varies significantly by season, with peak differences observed during summer and reduced effectiveness in winter months. Analysis of the data reveals an average temperature decrease of 3.07 °C during summer, which exceeds the annual average decline. Conversely, during winter, the average decrease is more modest at 0.86 °C.

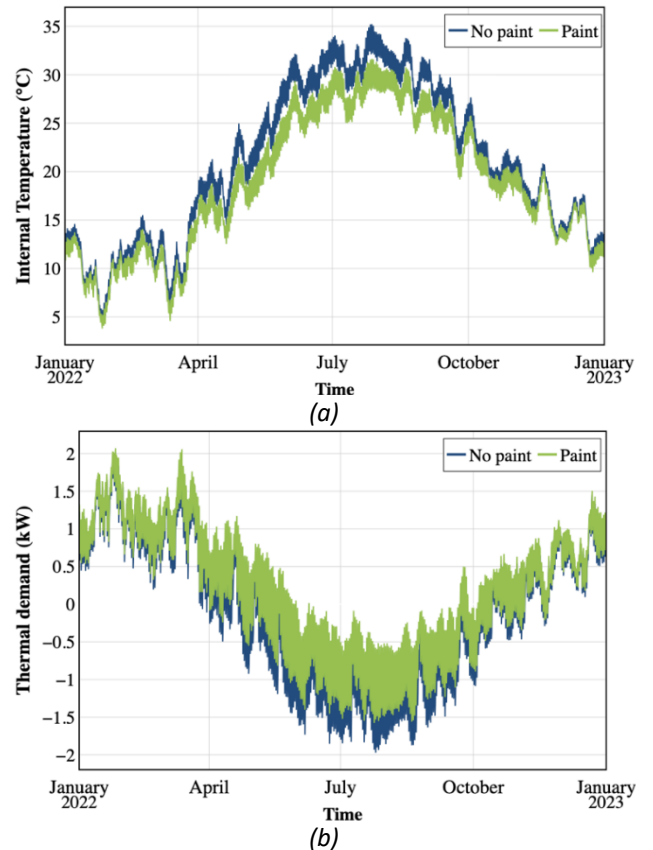


Fig. 5. East-facing flat in Athens, Greece: (a) Indoor temperature; (b) thermal demand.

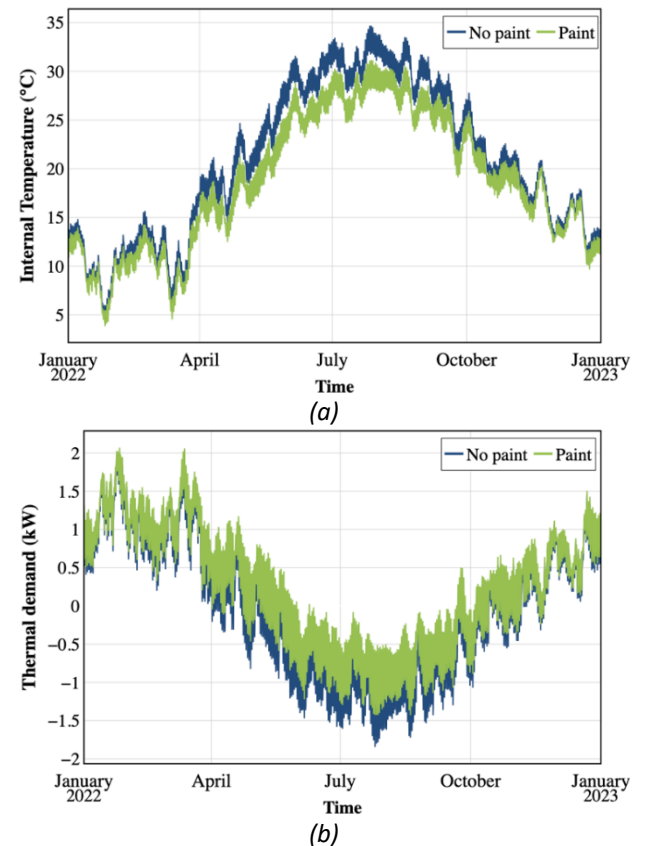


Fig. 6. North-facing flat in Athens, Greece: (a) Indoor temperature; (b) thermal demand.

In the east-facing flat, the average annual temperature decrease was 2 °C, with a maximum difference of 4.28 °C on 28 June at 05:00. The highest temperature differences are observed during the summer months (indicated by pronounced peaks in the middle of the graph), while in winter the impact is less pronounced. Further analysis reveals that during summer, the average internal temperature decreases by 3.12 °C, which is greater than the annual average decrease. In contrast, during winter, the average decrease is smaller, at 0.86 °C, as expected.

3.1.2 Implications on thermal demand

For the north-facing flat, applying cooling paint reduced the average hourly cooling demand from 0.40 kW to 0.26 kW (a decrease of 0.14 kW), while slightly increasing the heating demand from 0.45 kW to 0.54 kW (an increase of 0.09 kW). The annual total thermal load was 6,947.91 kWh for the painted case compared to 7,395.19 kWh for the unpainted case, representing an overall annual reduction of 447.28 kWh.

Similarly, for the east-facing flat, the average hourly cooling demand decreased from 0.43 kW to 0.28 kW (a reduction of 0.15 kW), with heating demand rising from 0.44 kW to 0.53 kW (an increase of 0.09 kW). The annual total thermal load for the painted case was 7,138.04 kWh, compared with 7,640.93 kWh for the unpainted case, yielding an overall annual reduction of 502.89 kWh. Key information is summarised in Table 2.

Results from Section 3.1 show that the cooling paint substantially reduces summer indoor temperature and cooling load for a flat located in Athens, with the most pronounced effects occurring during early morning hours of summer days. However, the reduction in solar heat gain also produces a modest increase in heating demand during winter months. The magnitude of the benefit is slightly greater for an east-facing orientation compared to a north-facing one.

Table 2: Summary of thermal demand for flats in Athens

Flat orientation and paint use	Mean internal temperature, °C	Annual thermal load, kWh
North, no paint	20.66	7,395.185
North, paint	18.68	6,947.907
East, no paint	20.90	7,640.93
East, paint	18.90	7,138.038

3.2 Flat in Marseille, Southern France

Simulation results for the flat in Athens in Section 3.1 indicate that east-facing flats perform slightly better than north-facing flats. Thus, results in this section consider

the worst-case scenario in terms of cooling effectiveness, a north-facing orientation, for a flat in Marseille. Results are shown in Fig. 7 for the year 2022.

3.2.1 Reduction in internal temperature

Application of cooling paint resulted in an average annual internal temperature decrease of 1.40 °C, with the maximum reduction of 3.00 °C occurring on 16 May. These results indicate a substantial effect in internal temperature during the summer months. Seasonal analysis showed mean reductions of 2.17 °C in summer, 1.65 °C in spring, 1.23 °C in autumn, and 0.72 °C in winter. During winter a limited impact was expected as the solar resource is reduced. This effect translates to a smaller increase in heating loads during the heating season.

3.2.2 Implications on thermal demand

The painted flat exhibited an average hourly heating load of 0.84 kW, compared to 0.74 kW for the unpainted case (+0.10 kW). Conversely, the average hourly cooling load decreased from 0.19 kW when a cooling paint is not applied to 0.12 kW when it is included, representing a reduction of 0.07 kW. Annual total thermal loads were 8,410.95 kWh for the painted case and 8,175.10 kWh for the unpainted case, indicating an overall annual increase of 235.85 kWh with the application of cooling paint.

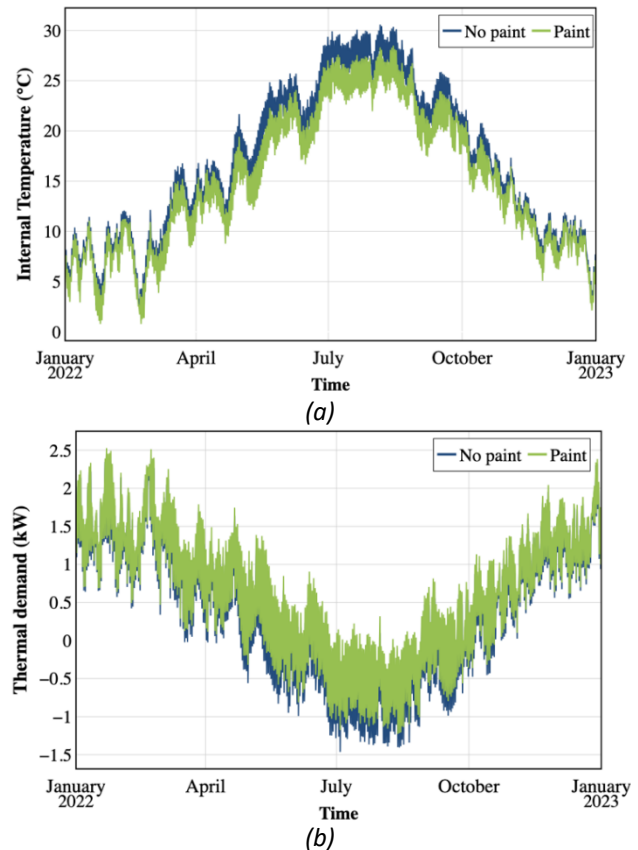


Fig. 7. North-facing flat in Marseille, France: (a) Indoor temperature; (b) thermal demand.

Cooling paint in Marseille effectively reduces internal temperatures, particularly during summer months, leading to decreased cooling demand. However, the reduction in heat gains may increase heating demand, which in this location may outweigh cooling savings, resulting in a net increase in total annual thermal energy consumption. Key information is summarised in Table 3.

Table 3: Summary of thermal demand for flat in Marseille

Paint use	Mean internal temperature, °C	Annual thermal load, kWh
No paint	16.53	8,175.10
Paint	15.08	8,410.95

3.3 Use of cooling paints in the UK

Additional simulations were conducted for north-facing and east-facing flats in the UK to assess the effectiveness of cooling paints. The building parameters used to simulate these flats were borrowed from [31] and a typical layout was adopted. As a way of an example, the city of Cardiff in Wales was chosen as location, with corresponding weather information incorporated into the simulation. (Cardiff has a cooler climate than Athens or Marseille, classified as ‘Cfb’ in the Köppen-Geiger climate classification.) Simulation results for the year 2022 are shown in Fig. 8(a) for the north-facing flat and Fig. 8(b) for the east-facing flat.

From an analysis of the results shown in Fig. 8, the north-facing dwelling exhibited an average annual heating increase of 0.16 kW, while cooling savings were only 0.018 kW—resulting in a net rise in annual energy consumption of over 1,200 kWh. For the east-facing flat, a higher net increase of approximately 1,400 kWh per year was observed.

The results presented in this section show that the overall benefits of cooling paints in the selected UK location may be limited, as indoor temperatures and cooling demand are modestly reduced during the relatively mild summer period. However, during an extended winter heating season compared to Athens or Marseille, the reflective painted surfaces diminish beneficial solar heat gains, leading to increased heating requirements and thus consumption.

3.4 Potential applications and limitations of this work

The results presented in this paper suggest cooling paints offer a promising performance in areas with high cooling demand such as the Mediterranean region (in addition to their application in tropical climates). The paints may be applied to external walls and roofs to reduce indoor overheating and cooling loads. At a larger

scale, community-wide adoption could lower aggregate cooling demand across multiple dwellings, thereby reducing strain on local electrical networks—particularly during heatwaves and periods of peak load. The cooling effects will likely increase when the thermal emission properties of the paints are accounted for. These were not assessed here and thus require further investigation.

Given that simulation results indicate measurable reductions in cooling demand, cooling paints could be incorporated into retrofit programmes or considered alongside other passive design strategies in cities with Mediterranean climates. However, in cooler or more temperate regions, their role may be more selective—best applied to dwellings or surfaces with the greatest solar exposure or combined with other passive measures to optimise year-round performance.

Application of cooling paints in heating-dominated climates with limited cooling demand should be done with care as their use may inadvertently increase overall energy consumption, which in turn may reduce their cost-effectiveness. These aspects need to be considered carefully before adopting cooling paints as a passive cooling strategy for residential buildings in the UK. Further research into this area may be required, but this falls out of the scope of this paper.

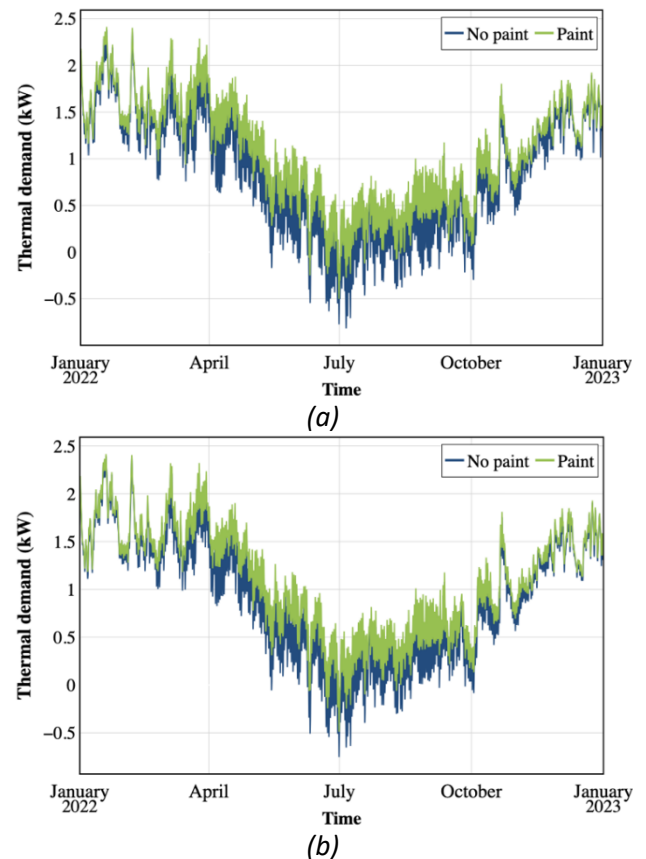


Fig. 8. Thermal demand for flats in Cardiff, Wales, UK: (a) East-facing orientation; (b) north-facing orientation.

4. CONCLUSIONS

This paper assessed the performance of passive cooling paints in flats, a very common type of residential dwelling, under Mediterranean climatic conditions. To this end, building performance simulations were conducted using the software IES VE.

In cities such as Athens and Marseille, externally applied cooling paints were found to significantly reduce indoor temperatures during summer, resulting in decreased cooling energy demand, while producing a modest increase in heating requirements during winter. The effectiveness of these coatings was influenced by building orientation, with east-facing flats showing slightly greater thermal benefits compared to north-facing flats.

In temperate, heating-dominated climates, such as those experienced in the UK, cooling paints provided limited cooling advantages and increased overall energy consumption due to reduced solar gains in winter, highlighting their limited applicability in such regions. These results indicate cooling paints may be an effective passive cooling strategy for mitigating thermal loads in Mediterranean climates, but their deployment in heating-dominated regions should be carefully assessed.

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